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The masking effect of background noise

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Research Department, Engineering Division
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THE MASKING EFFECT OF BACKGROUND NOISE

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Summary

In some studios, artists have been disturbed by audible breakthrough from adjacent areas, even though the measured sound insulation met the appropriate criterion.[1] *This arose because the background noise was quieter than expected, and failed to mask the breakthrough.*

In the work done, a masking relation, applicable to a studio environment, has been determined by a series of subjective tests. Above the levels at which the threshold of hearing has an influence, a simple power law was found. The results have been analysed in terms of critical band theory.

It is concluded that it is preferable to improve sound insulation than to increase the background noise level, although the cost implications have also to be considered.

Issued under the authority of

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION
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THE MASKING EFFECT OF BACKGROUND NOISE
A.P. Robinson, B.Sc.(Hons.), A.R.C.S.

1. Introduction

The work described in this report is intended to be used in the revision of an earlier BBC Report, 'Airborne sound insulation requirements in studio centres'.[1] The need for the work arose, in part, from experience in some studios, notably in the recently built Manchester headquarters, of audible breakthrough from adjoining studios. The background noise levels (generated by airflow, and by ventilation and other plant) in the studios which were suffering from the breakthrough were found to be significantly lower than the appropriate BBC criterion.[2] Thus the problem came about because the breakthrough was no longer masked by ventilation noise.

The aim of this investigation, therefore, was to simulate a studio environment and to determine by a series of subjective tests the relation between the background noise level and the level of breakthrough which was just not masked, using several different breakthrough sounds.

2. Theoretical considerations

In theory, linear masking would be expected, i.e. background noise level proportional to the level of breakthrough which is just not masked. With somewhat different conditions from those used here, one group of workers[3] found linear masking (their Fig. 9), whilst other workers[4] found an 8 dB increase in the masked level per 10 dB increase in the masking noise (their Fig. 6). In order to determine the masking law under conditions which resemble a studio environment as closely as possible, the present work was carried out.

Many aspects of the perception of sound are associated with the phenomenon of critical bands. One definition of the critical band is the bandwidth of a narrow-band random noise of constant effective sound pressure level, below which bandwidth the subjective loudness is constant, and above which the loudness increases. It is well established that the critical bandwidth is an approximately constant fraction of an octave at centre frequencies above about 800 Hz with a transition to an approximately constant frequency range below about 400 Hz. The fraction of an octave is variously given as one fifth to one quarter (Ref. 5, Fig. 1) or one third (Ref. 6, p.30).

The theory of critical bands suggests that as the level of the breakthrough signal is increased, it will first become audible in the critical band in which the signal to noise ratio is the greatest, and that the signal to noise ratio under these conditions is between 0 dB and −8 dB.

3. Details of experiment

3.1. The measurement of sound pressure levels

Throughout this report, sound spectra are given as the long-term r.m.s. sound pressure levels in third octave bands with ISO standard centre frequencies from 50 Hz to 4 kHz. The measurements were made with a precision sound level meter and a third octave spectrum analyser; the equipment was calibrated with a known sound source. The readings were corrected, where necessary, for the amplifier noise of the meter. A correction was also made for the directional characteristics of the microphone at frequencies above 1 kHz. The spectra were measured at the position of the subject's head, in the absence of the subject.

3.2. The test environment

The subjective tests were carried out in a free-field room because this was the only place available in which the background noise level was sufficiently low. The background noise spectrum is given in Fig. 1. Above 200 Hz, the noise level was below the instrumental noise and an upper limit to the background noise level is shown hatched. The use of a free-field room also makes it possible to set up well-defined sound pressure levels, and to measure these levels accurately.

It was decided to reproduce the ventilation noise through four loudspeakers arranged at the corners of a square with the subject sitting at the centre, to simulate the diffuse nature of ventilation noise. The BBC has adopted three criteria to specify the maximum allowable background noise in studios;[2] criterion (a) for radio light-entertainment studios, criterion (c) for radio drama studios, and criterion (b) for television and all other radio studios.

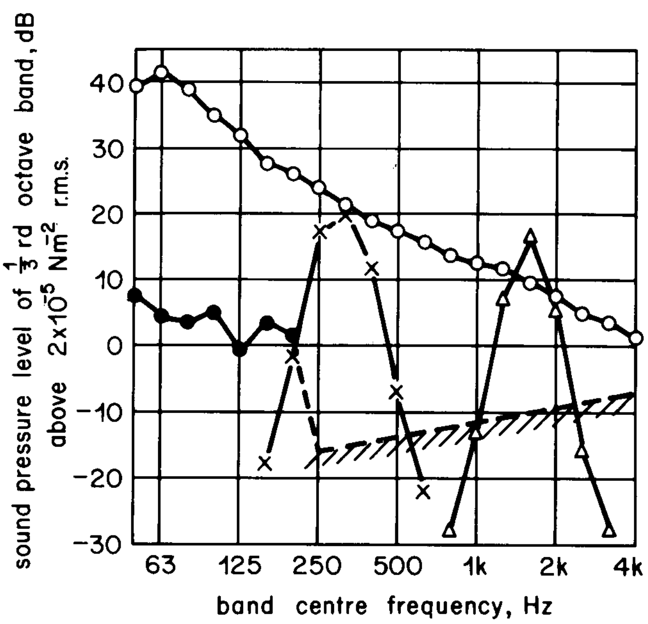

Fig. 1 - Sound spectra

○—○ Criterion (c) simulation
●—● Background in free-field room
△—△ 1·54 kHz noise band
×—× 303 Hz noise band

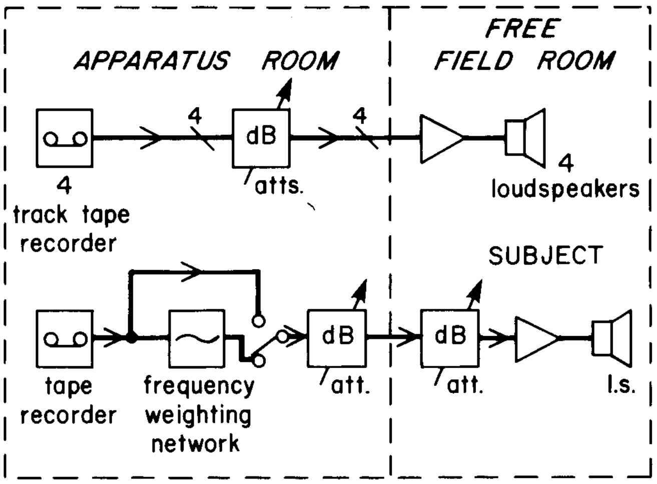

Fig. 2 - Block schematic

A number of measured spectra were examined, including some taken in the Manchester studios. They were all similar in shape to the BBC criterion curves, and it was decided that the simulated ventilation noise should be a random noise signal, weighted to the same spectral shape as the criteria. Interference between the sounds from the four loudspeakers in the free-field room was eliminated, by recording four independent noise signals separately on to magnetic tape. A noise reduction system was used to keep additional tape noise insignificant at high frequenices. A block schematic of the experimental arrangement is shown in Fig. 2. The spectrum achieved for the simulation of criterion (c) is given in Fig. 3, with the criterion (c) curve for comparison. It can be seen that the simulation is within 1½ dB except at the highest frequencies and in the band at 50 Hz. Several subjects commented that the simulated noise sounded very similar to ventilation noise.

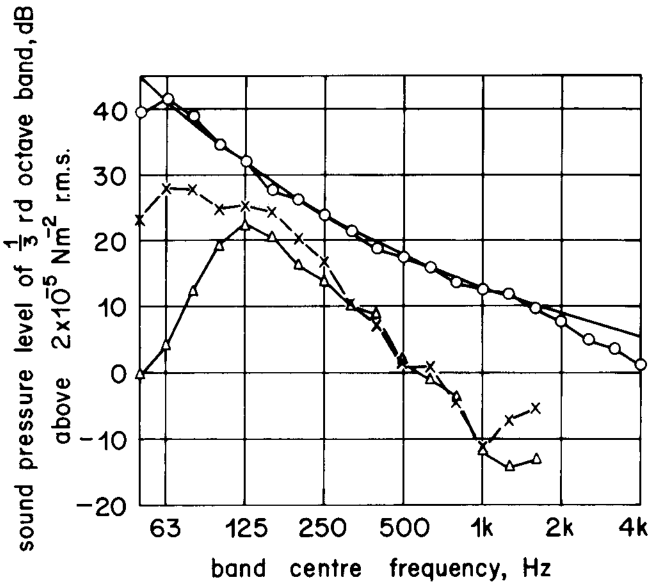

Fig. 3 - Sound spectra

o—o Criterion (c) simulation

—— Criterion (c)

△—△ Male speech item (frequency weighted)

x—x Pop item (frequency weighted)

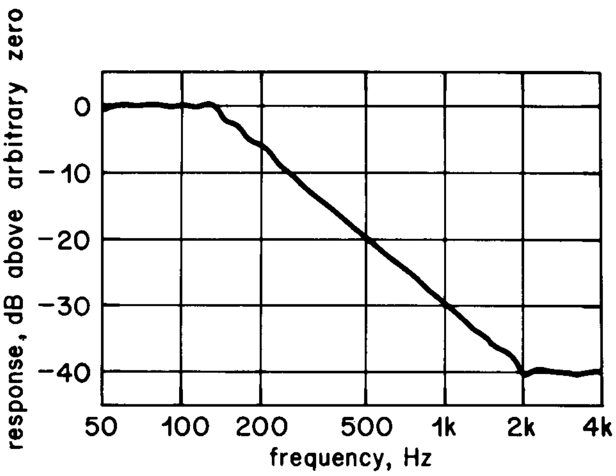

Fig. 4 - Characteristic of frequency weighting network

The breakthrough sounds were reproduced through a fifth loudspeaker, situated at the centre of a side of the square, in order to represent the directional character which breakthrough is likely to have. Two programme items were chosen, an item read by a trained male speaker, and an item of pop music. Each was recorded many times in succession onto magnetic tape, and the recordings were replayed through a frequency weighting network, see block schematic, Fig. 2. The response of the network, which is shown in Fig. 4, was an idealisation of the sound insulation characteristic of a typical double-leaf wall, the attenuation increasing by 10 dB per octave over a range of frequencies. The spectra of the speech and pop items, as reproduced in the free-field room using the frequency weighting network, are given in Fig. 3.

Two further items were chosen for the tests; these were obtained by passing a random noise signal through narrow-band filters. One filter had a centre frequency of 303 Hz and a 3 dB bandwidth of 0·27 octave, which is somewhat narrower than a critical band; the other filter had a centre frequency of 1·54 kHz and a 3 dB bandwidth of 0·29 octave, which is approximately equal to the critical bandwidth. It was hoped that these signals might sound like the noise of rotating machinery; in the event they did not, but they should represent the effect on the ear of an unwanted sound of fairly well-defined frequency. Moreover, it is much easier to specify the level of random noise than that of programme. The noise bands were also recorded, but were replayed without the frequency weighting network, see Fig. 2. The spectra of the noise bands are given in Fig. 1.

Two attenuators were placed in the breakthrough signal path, one under the control of the experimenter and one under the control of the subject. Care was taken to obtain accurate attenuations of up to 100 dB, constant over the range of frequencies of interest, and more than 80 dB was actually required in some cases.

3.3. Subjective test procedure

Fifteen experienced listeners took part in most of the tests. Some were professional radio broadcasters, the others were members of the BBC Research Department.

The aim of the investigation was explained briefly to each subject. The subject was told that simulated ventilation noise would be presented through the four loudspeakers at the corners of the room, at five different levels, the three loudest of which corresponded to the BBC criteria. The fifth loudspeaker would carry the breakthrough items, a newsreader and a pop music item, filtered to sound as if they had come through a wall dividing two studios. The subject was shown the attenuator with which he could control the level of breakthrough, and was asked to set it to a just perceptible level. Two or three attempts would be given at each noise level, the experimenter's attenuator being altered by a small random amount between attempts so that the readings on the subject's attenuator would not be meaningful on their own. The subject was asked to face towards the fifth loudspeaker, otherwise the sensitivity of his ears to the breakthrough would change.

The subject was also asked to make a few judgements of a different kind. He was to imagine that he was in a studio, waiting to do his part in a production, and to set the breakthrough to a level which would just disturb him. It was admitted that this was more difficult than judging a just perceptible level, and that the disturbing level might be the same or higher.

Most subjects attempted the tests in two sittings. At the second sitting, it was explained that the procedure would be the same as before, except that two random signals of narrow frequency range would be played through the fifth loudspeaker.

The five levels of background noise were: criterion (c) simulation, as shown in Fig. 3, 4 dB higher (corresponding to criterion (b)), 10 dB higher (corresponding to 1 dB above criterion (a)), and 4 and 10 dB lower.

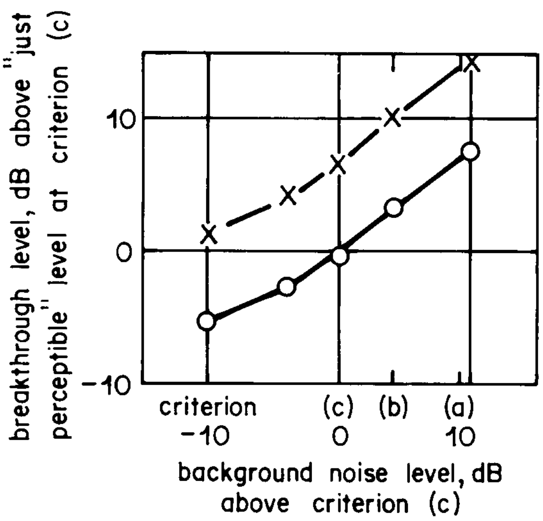

Fig. 5 - Masking law: overall mean results

X—X 'Just disturbing' breakthrough

O—O 'Just perceptible' breakthrough

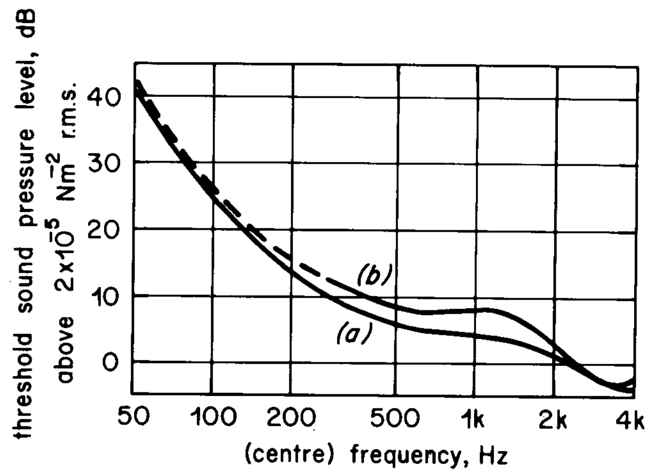

Fig. 6 - Threshold of hearing

(*a*) Pure tone (*b*) Octave band of noise

The results given by this kind of test can be influenced by the order in which the tests are presented: thus to reduce this effect, the noise levels were presented in several different sequences. The experimenter's attenuator was set so that the expected result for a just perceptible level was near the middle of the range of the subject's attenuator, thus the settings of the latter bore little relation to the background noise level.

4. Results

The spectra of the breakthrough items given in Figs. 1 and 3 have been plotted at the mean just perceptible level for criterion (c) background noise. The spectrum of this background noise is also given, for comparison. Fig. 5 shows the mean masking law for just perceptible breakthrough and for just disturbing breakthrough, with all the levels referred to the just perceptible level for criterion (c). More detailed results are given in the Appendix; the masking law for each breakthrough item is given separately, calibrated in sound pressure levels. The curves in Fig. 5 have a slope of 8 dB per 10 dB at the higher levels; the slope becomes less at lower levels.

Curves for the threshold of hearing are given in Fig. 6 to aid interpretation. Curve (*a*) is the ISO recommendation for pure tones.[7] Curve (*b*) was obtained by Robinson and Whittle for octave bands of white noise. (This curve is taken from their Fig. 8 as their final results, Fig. 14, contain a correction which is not needed here.) Fig. 6 shows that the sound pressure levels at threshold for pure tones and for octave bands of noise differ by less than 3 dB over most of the frequency range. The threshold of hearing for third octave bands of noise would be similar to the tone and octave band thresholds. Ref. 9 gives additional background information.

5. Discussion of results

The subjects commented that the loudness of the trained speaker's voice was remarkably constant, whereas the level of the pop music item varied a good deal, making it much more difficult to obtain a satisfactory setting of the attenuator. The results show that the loudness of the pop music item varied typically over a range of about 4 dB. The main difficulty with the noise bands was to ensure that one was actually hearing, and not imagining the sound. The acclimatisation of a subject to the conditions in the free field room had very little effect upon his responses, in other words, the masking effect of a given level of background noise is much the same, whether or not the subject is aware of the background. The absolute background in the room was sufficiently low to have a negligible effect even at the lowest sound levels used.

Applying the theory of Section 2, both the male speech and pop items should first become audible in the critical band centred on about 160 Hz. At this frequency, the critical bandwidth is about 100 Hz. An approximation to the sound pressure levels in this band was obtained by summing the power levels in the third octave bands centred on 125 Hz, 160 Hz and 200 Hz. The signal to noise ratios in the 160 Hz critical band for the male speech and pop items with reference to the ventilation noise, as drawn in Fig. 3, are about −8½ dB and −5½ dB respectively. However, it is likely that the ear tends to respond to the peaks in programme, so that it is only while the signal to noise ratios are somewhat larger that the breakthrough is heard. Also, the peak to mean ratio for the speech item is between 3 dB and 6 dB higher than that for the pop music item, which agrees fairly well with the difference between the signal to noise ratios given above.

The critical bandwidth at a frequency of 303 Hz is about 100 Hz. Thus, for the 303 Hz noise signal, an approximation to the sound pressure levels in the critical band was obtained by adding the sound power in the 315 Hz third octave and half the power in the 250 Hz third octave. This gave a critical band signal to noise ratio, for the spectra as plotted in Fig. 1, of −3 dB. At 1·54 kHz, the critical band is one third of an octave wide, or slightly less. The signal to noise ratio for the 1·54 kHz noise signal, taken in the third octave at 1·6 kHz, is nearly +7 dB, which is an unexpected result. This appears to be due to 'remote masking', that is, the much higher levels in the ventilation noise at lower frequencies are having a masking effect which extends to frequencies well above the critical band.

The masking relation, Fig. 5, is a straight line at the higher levels tested, but it is not possible to say whether it continues in this way, as the sound level at which the ear begins to generate significant non-linear distortion may have been reached. At lower levels, the masking relation flattens out, as it approaches the (unmasked) threshold of hearing for the breakthrough sound. In an attempt to obtain a straight line at the lower levels, an effective noise level was plotted on the x-axis, which was obtained by adding a noise level equal to the threshold of hearing, to the ventilation noise. This was done because it has been shown that under certain conditions, the threshold of hearing is connected with the level of physiological noise (blood flow, etc.) in the ears. This was an approximate procedure because no data were found for the threshold of hearing for critical bands of noise. It showed that this was an insufficient explanation for the shape of the curves; indeed, the detection of sound near threshold is a difficult topic.

There is a number of factors which contribute to the spread of the results for each test condition. The main sources of instrumental error were variations in the output from the magnetic tape and in the sensitivity of the loudspeaker units, as the ambient conditions changed; the absolute sound pressure levels were checked from time to time. There were also slight errors in the logarithmic law of the attenuators and the spectrum analyser. However, instrumental errors were not very significant.

A subject's judgement varies, but the subjects were found to be surprisingly consistent. Most subjects gave a spread of about 2 dB on repeated tests. The changes in the level of the pop music item have already been referred to. The effect of the latter two factors upon the spread of the results was reduced by including one average figure for each subject and for each test condition, in the results. The largest part of the variation in the results came from the differences between the opinions of different subjects, and the standard deviation of the individual results is essentially a measure of these differences. The standard errors of the just perceptible judgements were mostly between 3 dB and 5 dB, and for the just disturbing levels, mostly between 4 dB and 6 dB.

6. Conclusions and recommendations

A masking law for background noise has been determined in relation to the BBC's criteria for background noise in studios. A range of breakthrough signals, representative of a wide variety of sounds, has been used. The results for two conditions, just perceptible breakthrough and just disturbing breakthrough, referred to the just perceptible level at criterion (c), are given in Fig. 5. Sound insulation requirements may be obtained directly from Fig. 5. For example, if the background noise in a studio is reduced by 10 dB from criterion (c), then the sound insulation from adjacent areas need to be increased by about 5 dB if the subjective effect of the breakthrough is not to change.

The results should, however, be applied with caution. The slope of the masking law, and the threshold of hearing both depend upon the nature of the breakthrough sound. (See detailed results in Appendix.) If the sound pressure levels given are used to obtain sound insulation requirements from first principles, further care is required, since only the average power level of the programme items has been measured, only one wall insulation characteristic, Fig. 4, has been tested, and since an allowance for inter-subject differences is needed so that a sufficiently large proportion of subjects will be satisfied. It would be useful to make a statistical analysis of the two programme items in the same way as it was done for the survey of sound pressure levels,[10] to allow the present work to be related more readily to the survey results.

In a studio in which audible breakthrough is disturbing the artists, one may either increase the background noise level to mask the breakthrough, or improve the soundproofing, or a combination of the two. It would seem best, except where it would be unduly expensive, to improve the sound insulation, since the criteria for background noise are maximum acceptable levels, and since a 1 dB increase in sound insulation reduces the background noise needed for masking by more than 1 dB.

7. Acknowledgements

The author is grateful to David Meares for his help and advice given throughout the course of this work. The author is also grateful to Tony Woolf, Mike Batho, John McCulloch, Margaret Steven and Tony Kime, who travelled from London to take part in the subjective tests.

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Appendix

Detailed results

The results of the subjective tests for male speech, pop music, 303 Hz noise band and 1·54 kHz noise band are given separately in Figs. A.1, A.2, A.3, and A.4 respectively. An approximation to the sound pressure levels in the appropriate critical bands was obtained as described in Section 5. The critical band sound pressure level of each item is plotted against that of the background noise for the 'just perceptible' and the 'just disturbing' conditions. The background levels corresponding to criteria (a), (b) and (c) are marked.

The graphs are all similar to Fig. 5. The two curves in each graph are nearly parallel to each other. The slopes of the straight portions vary from about 6½ dB to 9½ dB per 10 dB and the differences between the perceptible and disturbing levels range from about 5 dB to 10 dB.

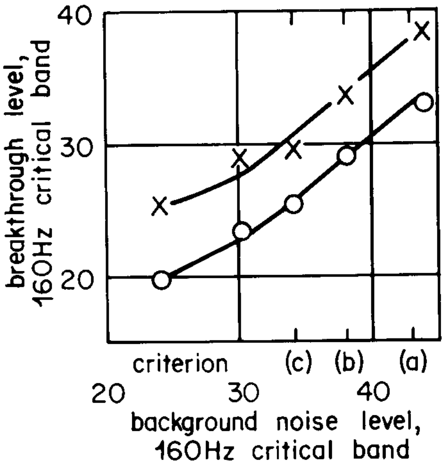

Fig. A.1 - Male speech

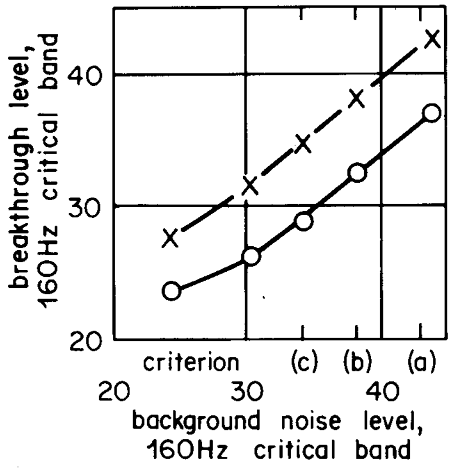

Fig. A.2 - Pop music item

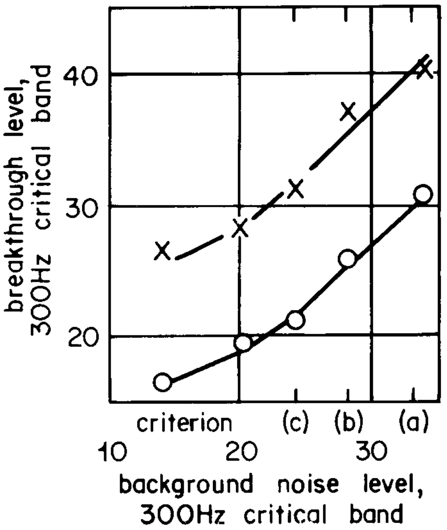

Fig. A.3 - 303 Hz noise band

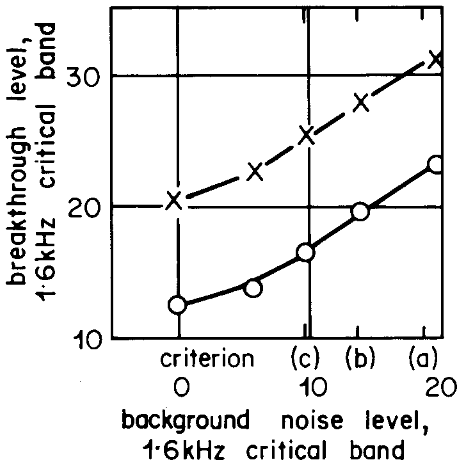

Fig. A.4 - 1·54 kHz noise band

Figs. A.1 — A.4 - Masking law: mean results for individual items

Sound pressure levels of stated bands, dB above 2 x 10^{-5} Nm^{-2} r.m.s.

X——X 'Just disturbing' breakthrough   O——O 'Just perceptible' breakthrough

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